NNUN Education and Outreach

NNUN provides extensive hands-on and web-based education, training, and mentoring in nanotechnologies and the underlying disciplines. These include

- Nanocourses (offered for > 10 years) that are also available on the web in streaming video (since 1999) (http://www.cnf.cornell.edu/nanocourses/nanocourse.html)
- Extensive technical processing and equipment information through its web-site (http://www.nnun.org)
- Web-based software for modeling and design
- Hands-on undergraduate research (REU) that has had majority of students go to graduate studies
- During 2001, NNUN supported the experimental education of over 1100 graduate and undergraduate students
  - ~ 300 PhD awards depended on NNUN resources
- During 2001, NNUN supported effort of >150 small companies
  - >25 companies seeded have been seeded by research from NNUN
- Extensive use of workshops (US-India, E-beam, Chemical Nanotechnology, Nanoprocessing techniques during 2001-2002), booths at conferences, research publications, and multi-media technology

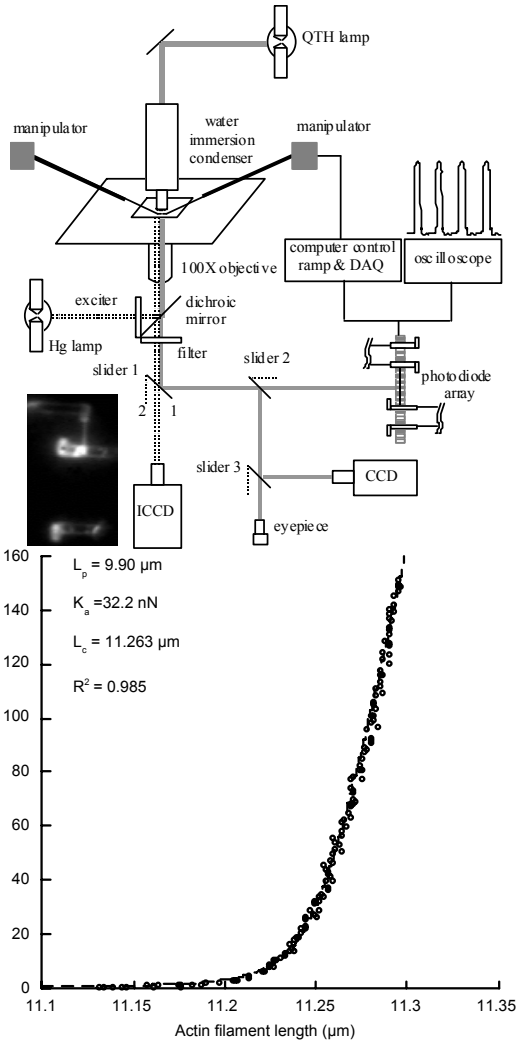
NNUN funded by NSF and research funded by DARPA and NSF,

NNUN National Nanofabrication Users Network

Elasticity of Actin Filament Using Nanofabricated Cantilevers

G. H. Pollack, Univ. of Washington

F-actin is a critical component of myofibril, and of virtually all-eukaryotic cells. Its elastic behavior is unclear and hence our understanding of how muscle works remains incomplete. Ultra-small cantilevers fabricated at NNUN were employed to characterize the elasticity of single actin filaments from zero to maximal physiological tension, P_o for the first time. The length-tension relation is nonlinear at low tension (0-50 pN) with a strain of ~0.4-0.6%, linear at higher tensions (~50-230 pN), and the stretching stiffness of a single rhodamine-phalloidin-labeled 1 mm long F-actin is 34.5 ± 3.5 pN/nm. This relationship could be characterized by an entropic-enthalpic worm-like chain (WLC) model. In the nonlinear portion, most of the energy is consumed in overcoming thermal undulations (filament's interaction with surrounding solution) and linear portion to intrinsic stretching elasticity (~persistence length of ~8.75 mm). *These results suggest that F-actin is more compliant than previously thought, and that thin filament compliance may account for a substantial fraction of sarcomere's elasticity*.



NNUN funded by NSF and research funded by NIH

NNUN National Nanofabrication Users Network

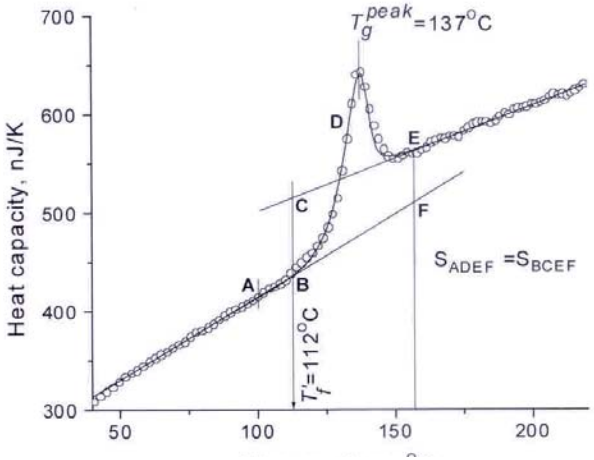
NanoCalorimetry of Polymers and Metals

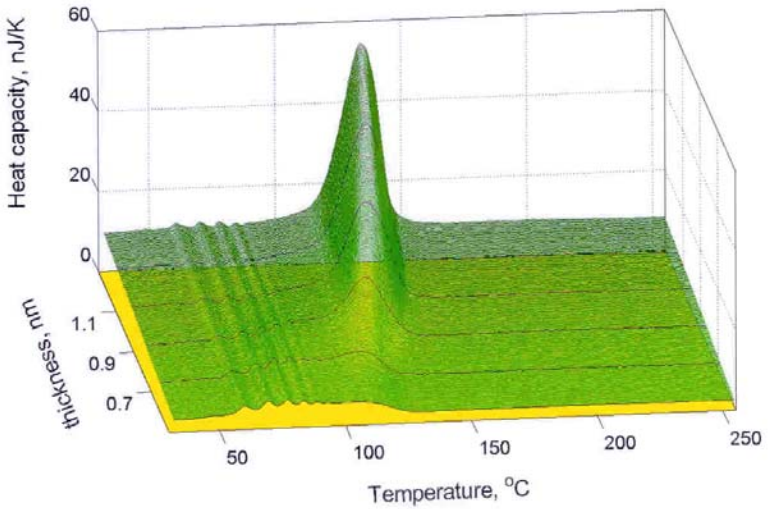
L. H. Allen, Univ. of Illinois

Nanocalorimetry, using structures fabricated at NNUN, has been applied to precise heat capacity measurements of polymers and metals for very thin films.

Ultra-thin polymer films exhibit large shifts in glass-transition temperature (T_g) whose underlying nature is not yet well-understood. The precise measurements on spin-cast polystyrene [Macromolecules, 35, 1481 (2002)] of this effort are providing information that can be used to understand the energetics of polymer growth at 10's of nm.

The technique has also been applied to obtaining "Cp vs. T vs. t" in-situ data during growth. Formation of magic number size particles [Phys. Rev. Lett. 85, 3560 (2000)] was discovered and size dependent melting [Phys. Rev. B., 62, 10548 (2000)] have been elucidated using the measurements.





NNUN funded by NSF and research funded by NSF, and ACS

National Nanofabrication Users Network

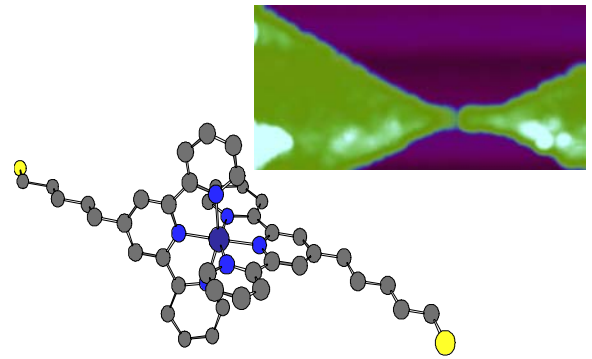
Single Atom Single Electron Transistor

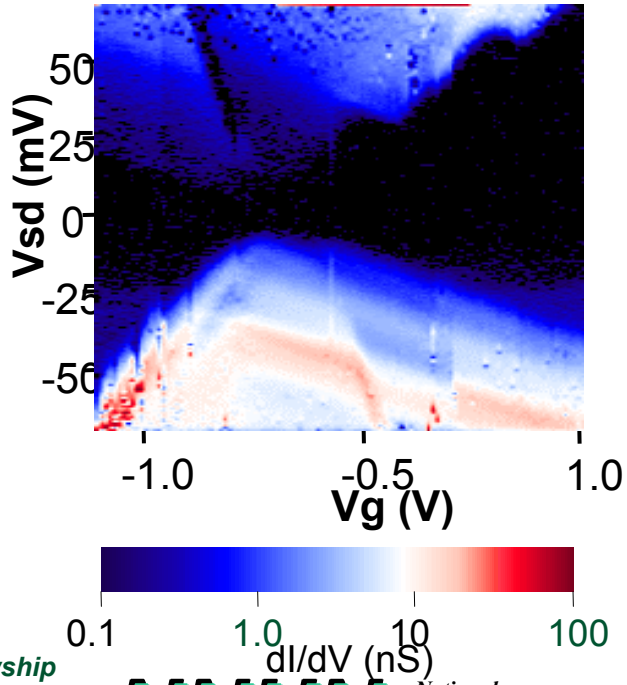
D. Ralph, P.McEuen, H. Abruna et al.,Cornell Univ.

For the first time, phenomena such as Coulomb blockade and Kondo effect have been studied in single atom systems using a single-electron transistor. The high resolution structures are fabricated at NNUN with the ~2 nm gaps defined using electromigration and the synthesized molecule (4'-(5-Mercaptopentyl)-2,2':6',2''-terpyrindinyl thiol arms with Co atom in center) of octahedral coordination dropping in between the electrodes.

Strong single-electron effects are observed with transport showing Coulomb blockade, Kondo effect, effects of the molecular barriers, and possible effects from vibrations and Co^{2+} and Co^{3+} states [J. Park et al. Nature 417, 722 (2002) and W. Liang et. al. Nature 417, 725 (2002)].

These are the first observations of atomic phenomena using direct electron transport measurements.





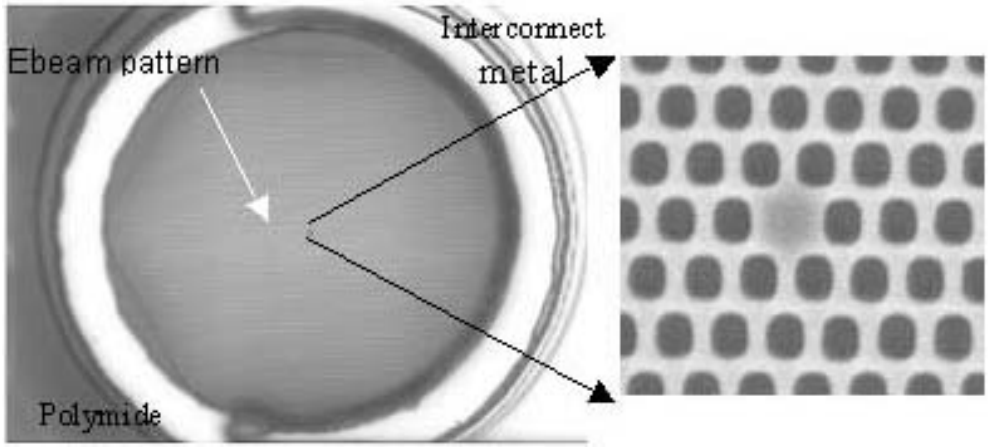
NNUN funded by NSF and research funded by NSF, Packard Foundation, DOE, and Dept. of Education GANN Fellowship

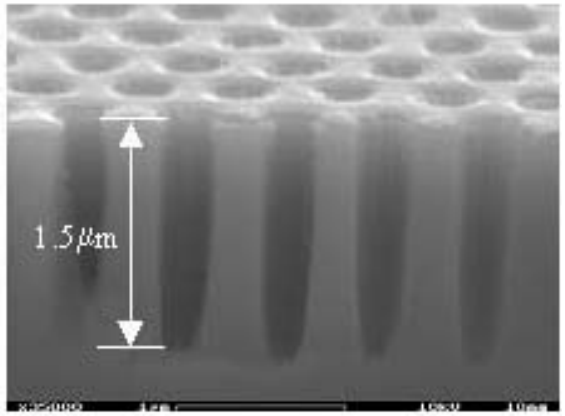
NATIONAL SCIENCE FOUNDATION

NNUN National Nanofabrication Users Network

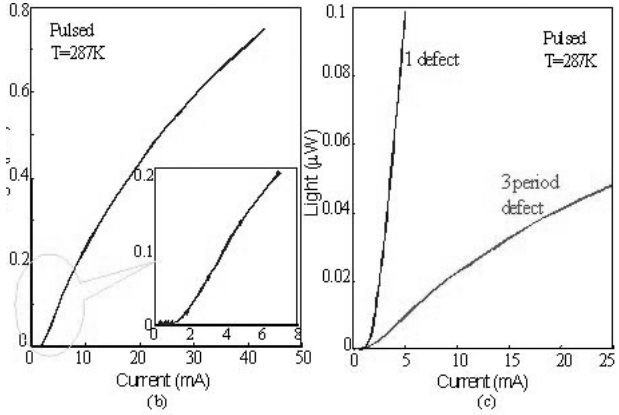
1.55 μm and 1.3 μm Microcavity Light Source

P. K. Bhattacharya, Univ. of Michigan





Low power and compact light wave sources are critical to communications with preferred wavelengths for long distance at 1.3 and 1.55 μm. The microcavity light sources at this wavelength are extremely difficult to make because of the combination of materials and processing techniques required. This effort [J. Sabarinathan et al., Indium Phosphide and Related Materials Conference,Stockholm(2002)] is the first to successfully make electrically pumped microcavity light sources using InP substrate and show low threshold current.



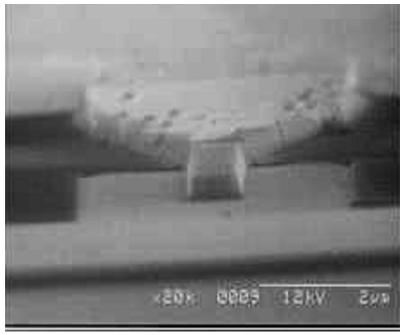
NNUN funded by NSF and research funded by ONR and ARO

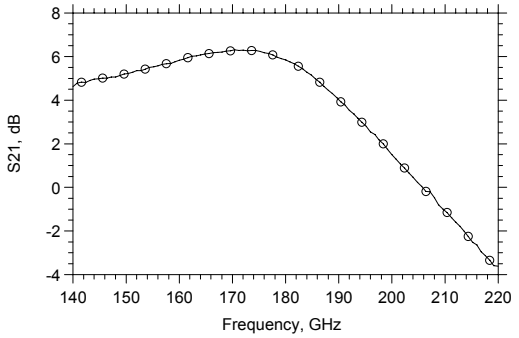
Bipolar Transistors for 140-220 GHz Amplifiers

M. Rodwell, UCSB

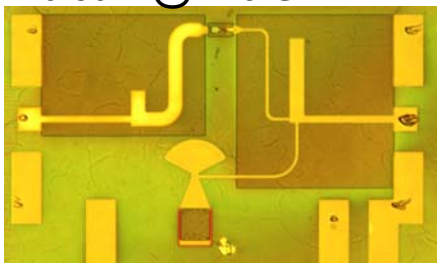
Amplification for analog applications at extremely high frequencies (100's of GHz) is an extremely challenging problem requiring the use of unusual materials (compound semiconductors), extremely small dimension (~100 nm) devices, low parasitics, and ambitious RF circuit design. This effort has significantly extended the reach of gain and frequencies achievable in semiconductor transistors by use of InP-based bipolar structures. Single and multiple stage circuits have been demonstrated operating at frequencies close to 200 GHz.

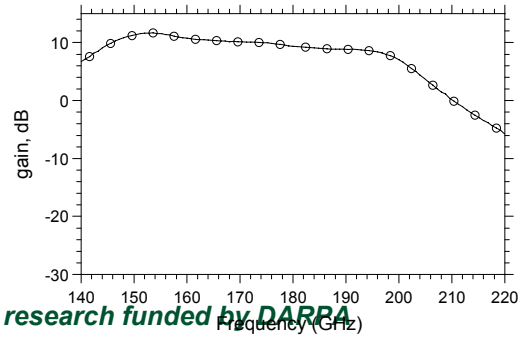
6-11 dB power gain @ 200 GHz



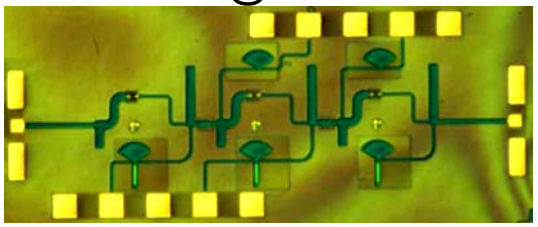


1-transistor amplifier: 6.3dB @ 175 GHz





3-transistor amplifier: 8 dB @ 195 GHz



NNUN funded by NSF and research funded by DARPA

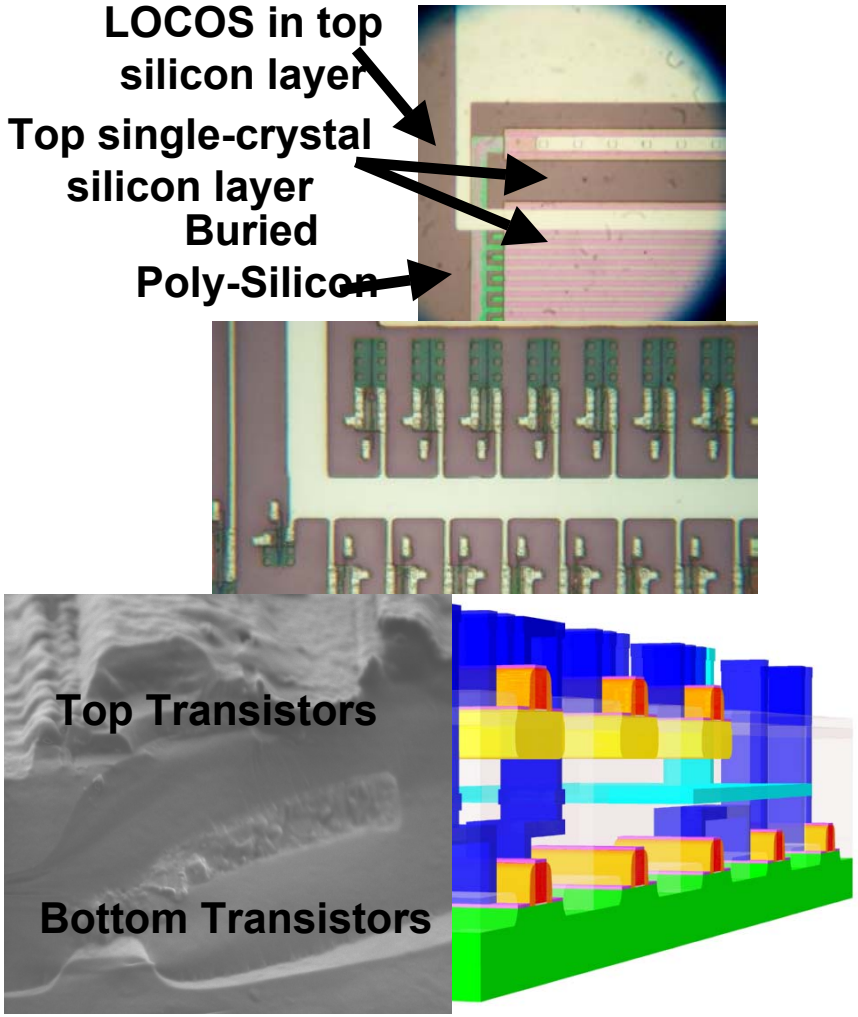
NNUN National Nanofabrication Users Network

3D Integration in Si Nanoelectronics

S. Tiwari, Cornell Univ.

Three-dimensional integration incorporating planar transistors, vertical interconnections, low power, device-level programmability, and isolating ground planes, is one of the approaches by which silicon can continue with higher levels of integration. This effort has succeeded, for the first time, in developing a low temperature silicon-process compatible thin single-crystal silicon layering technique together with incorporation of tungsten in between device planes, and has demonstrated attractive device performance in three-dimensionally integrated structures with less than 1 μm inter-plane separation [L. Xue et al., Proc. of IEEE International SOI Conf. (2001), H. S. Kim et al., Proc. of SSDM (2002), and C. Liu et al., Proc. of IEEE International SOI Conf. (2002)].

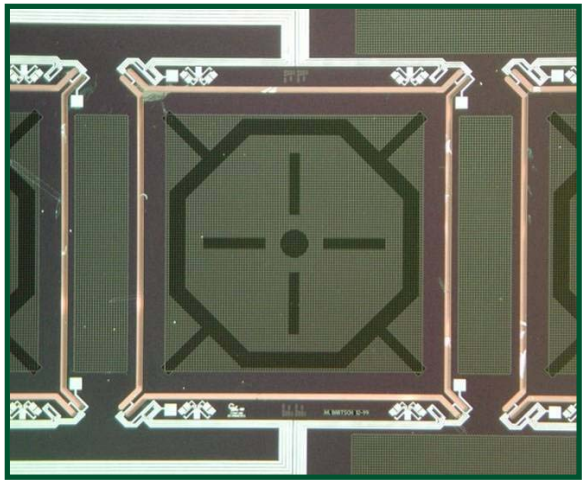
The success of the demonstrations makes possible giant scale system-on-chip applications in digital and mixed-signal applications.



NNUN funded by NSF and research funded by DARPA and NSF,

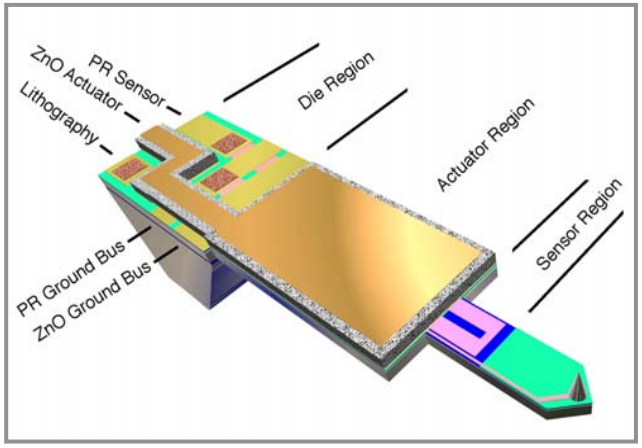
MEMS for Studying Insect Biomechanics
M. Bartsch, Stanford University

- Study of insect biomechanics provides engineering insights:
  - Design cues for biomimetic robots
  - Small-animal scaling laws in nature
- Multi-axis micromachined sensors enable measurement of insect running forces
  - Previous methods could resolve 0.1mN forces for large insects - MEMS sensors resolve ~20nN forces
  - MEMS bandwidth & sensitivity reveal previously unseen running dynamics
  - First ever measurements of single leg forces produced by ants
- Work conducted w/ RJ Full (UC Berkeley)

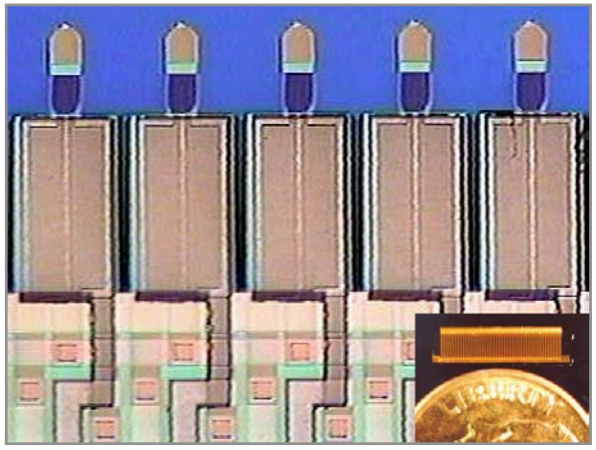


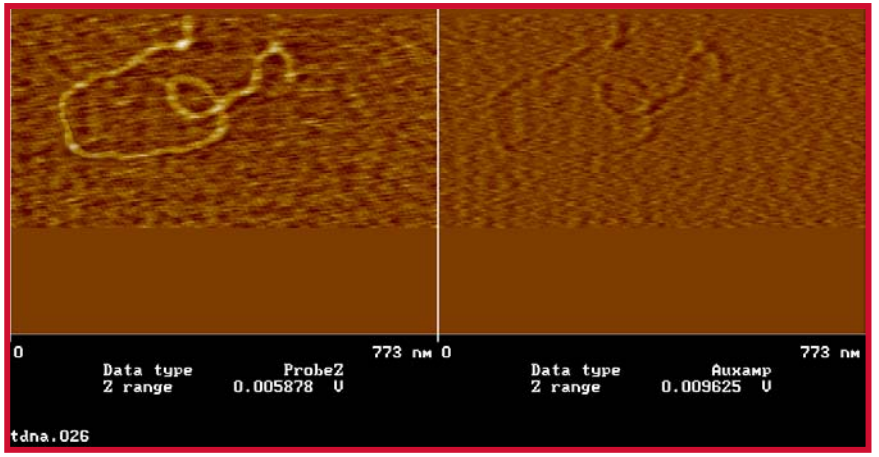
High-speed Atomic Force Microscopy for Biological Applications

C. Quate, Stanford University



We have increased the speed of scanning 10 fold through micromachined integration of the feedback actuator. The device (at left) is compatible with parallel operation, with an array of 50 independent probes (shown below left.) An image of a ladder DNA is shown below, with 10 nm resolution and over order of magnitude increase in speed.





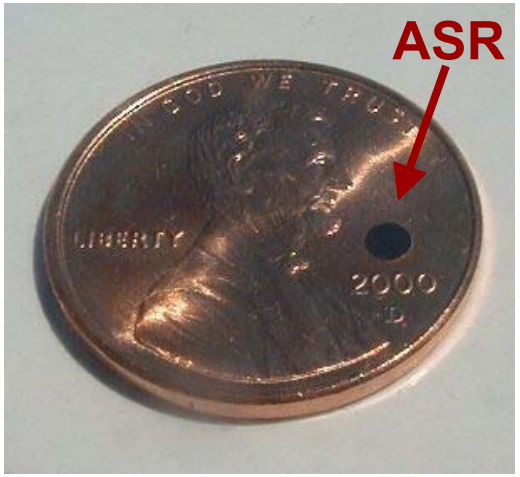
Optobionics - Artificial Silicon Retina (ASR)

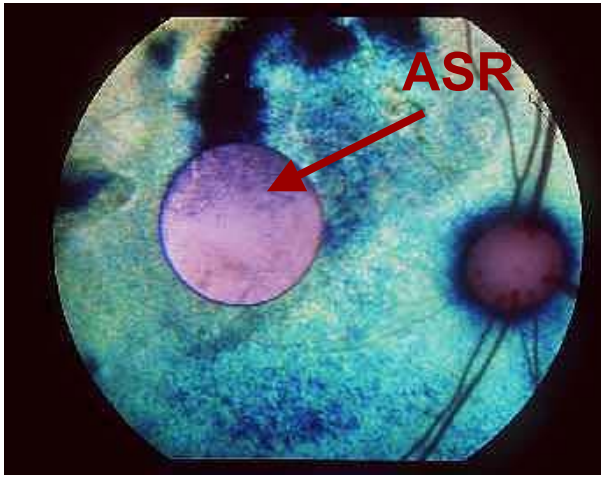
V. Chow, Optobionics Corp.

Optobionics has developed a retinal prosthesis to restore vision to people suffering from certain types of retinal disease.

- **Since beginning clinical trials In June 2000, surgical implantations of ASRs have been performed in six patients.**
- **The implants continue to function electrically and remain stably in position. There are no signs of ASR degradation or rejection, no infection, inflammation or retinal detachment have been observed at this time. All patients report improvement in vision to varying degrees.**

  (Lower image: Fondus photograph of implanted ASR in a patient.)

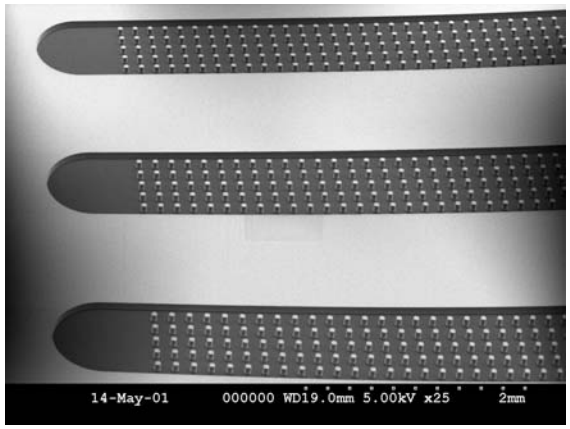


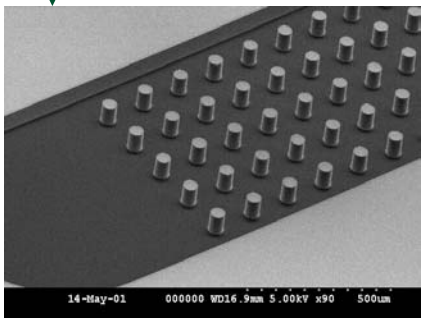


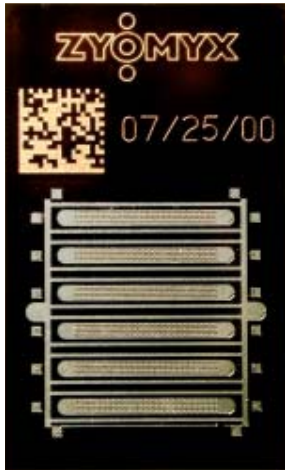
High Density Chip for Proteomics

P. Wagner, ZYOMYX

- Multi-channel chip (250 protein binding assays per channel)
- Up to 10,000 assays per cm^2
- 3D chip (50 microns diameter features)
- High throughput serial dispensing or proprietary parallel dispensing
- Improved surface chemistry for enhanced sensitivity and for reduced non-specific binding
- On-site production facility
- Visit us at: http://www.zyomyx.com







National Nanofabrication Users Network

Integrated Optics for Chip-based Electrophoresis

F. Lytle, Purdue University

- **Square hollow waveguides** are used to integrate measurement of absorption with chip-based analytical separations based on electrophoresis.
- **Simple fabrication:** Definition of waveguides is done in the same, single patterning step used to define the electrophoresis channel. The separation channel and waveguides (both 50 X 50 μm) are etched as a negative pattern into a silicon master which is used to cast a PDMS mold.
- **Light is guided by reflection** at the air-PDMS interface, not total internal reflection.
- **The waveguide has 60% efficiency** over a distance of 3.2 cm. A detection limit (S/N=3) of 200 μM fluorescein is obtained using a 50 μm path length and a simple photocell detector.